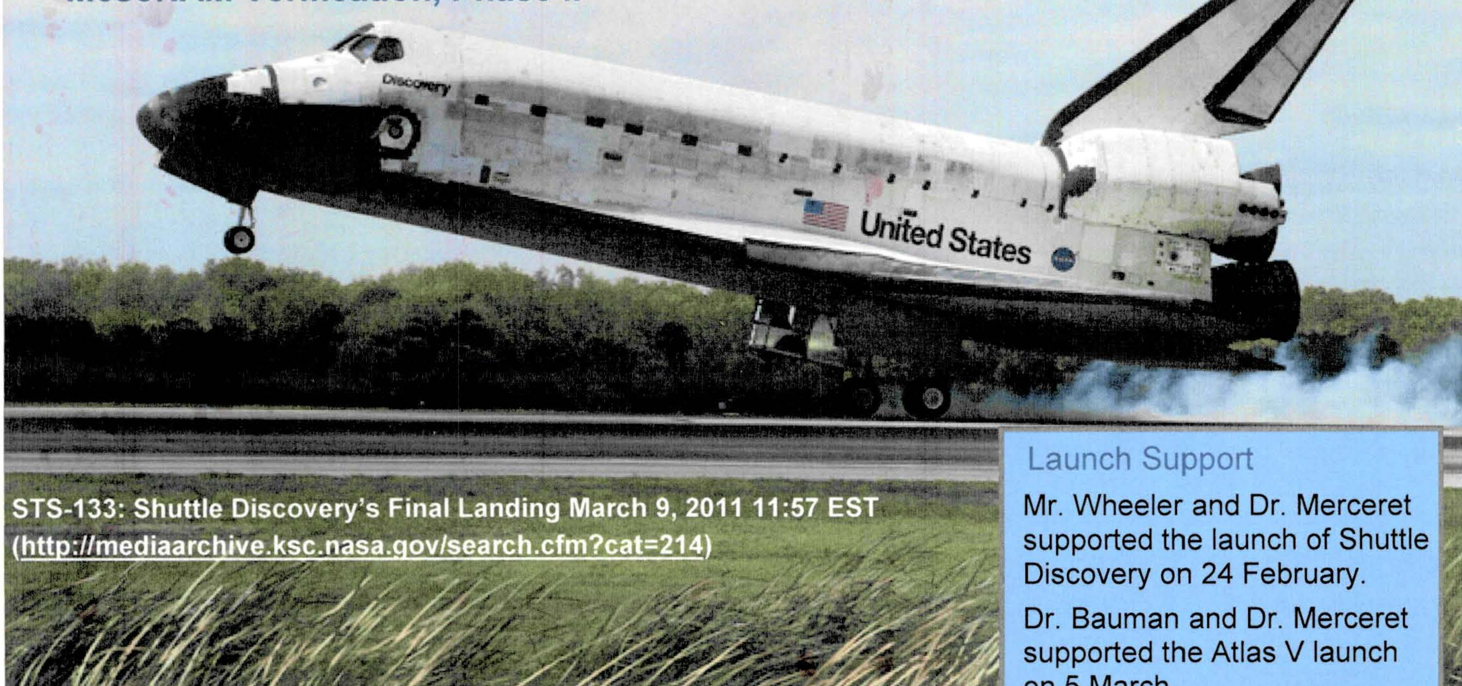
Applied Meteorology Unit (AMU) Quarterly Report

30 April 2011 Second Quarter FY-11 Contract NNK06MA70C

In this issue:



STS-133: Shuttle Discovery's Final Landing March 9, 2011 11:57 EST (http://mediaarchive.ksc.nasa.gov/search.cfm?cat=214)

Launch Support

Mr. Wheeler and Dr. Merceret supported the launch of Shuttle Discovery on 24 February.

Dr. Bauman and Dr. Merceret supported the Atlas V launch on 5 March.

Ms. Crawford and Dr. Merceret supported the Delta IV launch on 11 March.

The AMU Team completed one task, began another, and continued work on three:

- Dr. Watson completed the task to update the AMU-developed severe weather forecast tool, and began work on the second phase of verifying the performance of the MesoNAM weather model over Kennedy Space Center and Cape Canaveral Air Force Station.
- Ms. Crawford continued work to improve the AMU peak wind tool by processing and analyzing wind tower data to determine peak wind behavior during times of onshore and offshore flow.
- Dr. Bauman continued updating lightning climatologies for airfields around central Florida and created new climatologies for specific moisture thresholds as defined by Florida soundings.
- Mr. Wheeler completed a study for the 30th Weather Squadron at Vandenberg Air Force Base in California in which he found precursors in weather observations that will help the forecasters determine when they will get strong wind gusts at their northern towers.

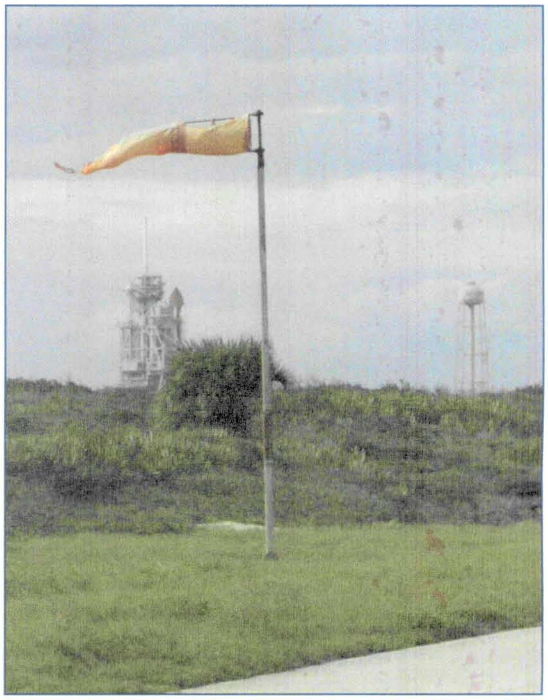
ENSCO

1980 N. Atlantic Ave., Suite 830
Cocoa Beach, FL 32931
(321) 783-9735, (321) 853-8203 (AMU)

Quarterly Task Summaries

This section contains summarizes of the AMU activities for the second quarter of Fiscal Year 2011 (January - March 2011). The accomplishments on each task are described in more detail in the body of the report starting on the page number next to the task name.

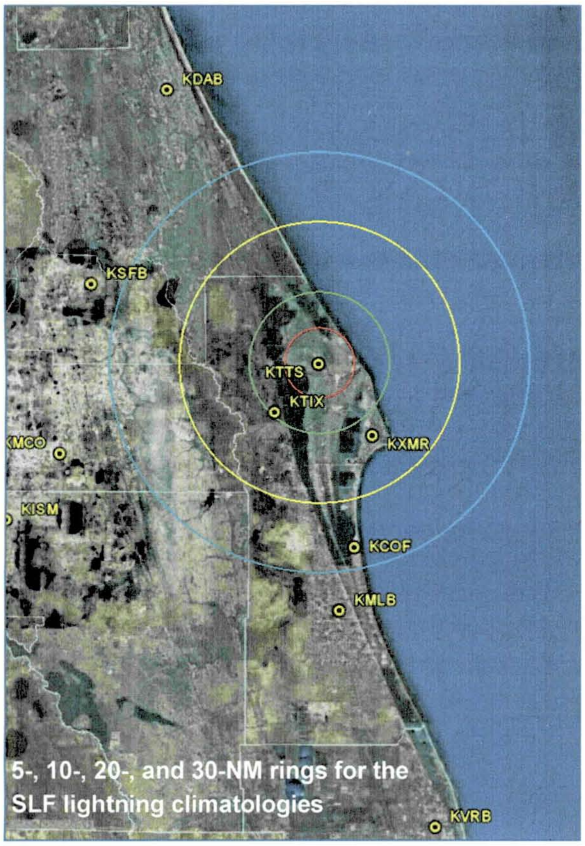
Peak Wind Tool for User LCC, Phase IV (Page 5)



Purpose: Recalculate the Phase III cool season peak wind statistics using stability as an added stratification. Peak winds are an important forecast element for launch vehicles, but the 45th Weather Squadron (45 WS) and Spaceflight Meteorology Group (SMG) indicate that they are challenging to forecast. Stability has long been known to have a strong affect on surface winds. Recalculating the statistics after stratifying by stability will make them more robust and useful to operations.

Accomplished: Determined that the tower data cannot be used for the stability stratification. The Cape Canaveral Air Force Station (CCAFS) soundings are being processed to determine if they can be used to determine stability with more accuracy. The tower data were stratified by on/offshore flow to calculate hourly climatological values for the 5-minute mean and peak speeds, gust factors, and the number of occurrences for each sensor on the towers and for each month. There appears to be a relation between the hourly values of a solar parameter and the gust factors.

Situational Lightning Climatologies for Central Florida, Phase V (Page 7)



5-, 10-, 20-, and 30-NM rings for the SLF lightning climatologies

Purpose: Update the existing lightning climatology to improve operational weather support to Kennedy Space Center (KSC), CCAFS, Patrick Air Force Base (PAFB), and commercial and general aviation across central Florida. The update includes adding more years of data to the database, adding more sites and adding stratifications for moisture and stability parameters. These updates will provide climatologies for new sites for which the 45 WS and National Weather Service (NWS) have forecast responsibility, and to help forecasters distinguish lightning days that are more active from those that are less active within the same flow regime.

Accomplished: Received National Lightning Detection Network (NLDN) data (May-September 1989-2010) from the 14 WS for the nine additional sites requested by the NWS in Melbourne, Fla. The data were stratified by precipitable water (PWAT) thresholds and new PWAT-based lightning climatologies were generated for 28 of the 32 airfields.

Quarterly Task Summaries
(continued)

Delta II at VAFB
Photo by Thom Baur/Boeing

Vandenberg Air Force Base North Base Wind Study (Page 8)

***Purpose*:** Analyze local wind tower, surface, upper air and sounding data from Vandenberg Air Force Base (VAFB) to find precursors to high wind events in the north base towers. The 30 WS states that terrain influences the unpredicted strong northeast winds that have been measured on several of the north base wind towers and exceed their 35 kt warning criteria. This study will examine those influences and document any precursors that may be found that will assist forecasters in analyzing their wind warning criteria.

***Accomplished*:** The VAFB wind tower data provided by the 30 WS were decoded and evaluated. Thirty of the 66 event days had all the data needed for further analysis. Surface and upper air charts were analyzed to determine the synoptic conditions for each event day, and peak wind direction and speed charts were developed and analyzed. The results showed that all of the high wind events began with a wind shift to the northeast followed by the strong winds within 2 hours of the shift.

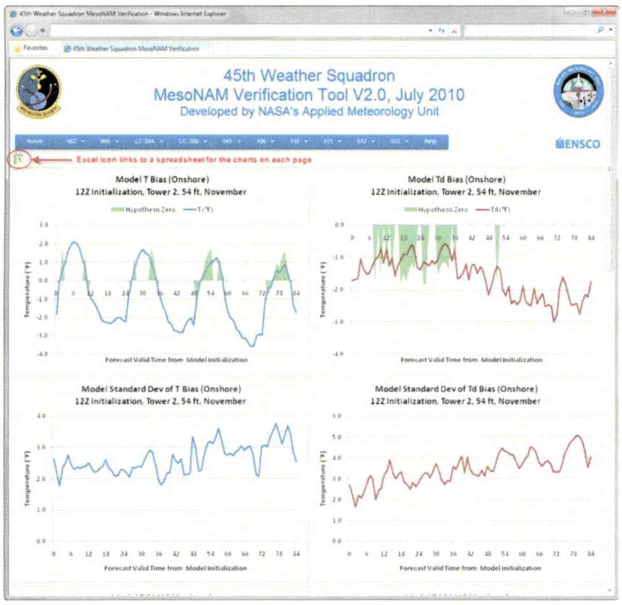
Upgrade Summer Severe Weather Tool Phase III (Page 11)

***Purpose*:** Upgrade the Summer Severe Weather Tool by adding another warm season and testing another statistical technique to determine if its performance can be improved. This task increases the period of record from 21 to 22 years and uses logistic regression to determine the appropriate predictors and provide a probability forecast. The performance of the logistic regression equations will be compared with the previous tool.

***Accomplished*:** Developed a four-predictor logistic regression equation by determining how each individual predictor contributed to the reduction of variance. The equation's performance was tested against that of the current severe weather forecast tool using four statistical tests. The results showed that the current tool outperforms the equation.

Tornado on KSC
Photo by anonymous USA employee

Quarterly Task Summaries
(continued)



MesoNAM Verification Phase II (Page 13)

***Purpose*:** Update the current tool that provides objective verification statistics of the 12-km North American Mesoscale (NAM) model (MesoNAM) for CCAFS and KSC. This tool helps the Launch Weather Officers understand the model's performance when they use it to evaluate launch commit criteria (LCC) during launch operations. The modifications include adding a year of observations and model output data to the original database. The objective analysis consists of comparing the MesoNAM forecast winds, temperature and moisture to the observed values at the KSC/CCAFS wind towers used to evaluate LCC.

Accomplished: The wind tower observations and MesoNAM forecasts needed for the task were acquired. The tower data were quality controlled (QC-d) and processed to remove unneeded time periods and fill in missing values. When the data were prepared, the mean value for each observed parameter was computed for each hour.

AMU ACCOMPLISHMENTS DURING THE PAST QUARTER

The progress being made in each task is provided in this section, organized by topic, with the primary AMU point of contact given at the end of the task discussion.

SHORT-TERM FORECAST IMPROVEMENT

Peak Wind Tool for User LCC, Phase IV (Ms. Crawford)

The peak winds are an important forecast element for the Expendable Launch Vehicle and Space Shuttle programs. As defined in the Launch Commit Criteria (LCC) and Shuttle Weather Flight Rules, each vehicle has peak wind thresholds that cannot be exceeded in order to ensure safe launch and landing operations. The 45th Weather Squadron (45 WS) and the Spaceflight Meteorology Group (SMG) indicate that peak winds are a challenging parameter to forecast, particularly in the cool season. To alleviate some of the difficulty in making this forecast, the AMU calculated cool season wind climatologies and peak speed probabilities for each of the towers used to evaluate LCC (Figure 1) in Phase I (Lambert 2002). In Phase III (Crawford 2010), the AMU updated these statistics with six more years of data, added a new time-period stratifications and created a graphical user interface (GUI) to display the desired values similar to that developed for SMG in Phase II (Lambert 2003). Based on recommendations from Phase III and observations by the launch weather officers (LWOs), the 45 WS tasked the AMU to stratify the data by stability and onshore/offshore flow and recalculate the climatologies and probabilities. These modifications will likely make the statistics more robust and useful to operations.

Data

Ms. Crawford received all Kennedy Space Center (KSC) and Cape Canaveral Air Force Station (CCAFS) wind tower network and CCAFS sounding data for December 2010 from Mr. Madison of Computer Sciences Raytheon (CSR) and the hourly Shuttle Landing Facility (SLF) pressure data from the 14 WS needed for the Richardson number calculations. She quality controlled and prepared these data for analysis using the S-PLUS® (Insightful Corporation 2007) statistical software package. The data are from the cool season months October through April 1995-2010, 16 cool seasons in the period of record (POR).

Stability Determination

Ms. Crawford calculated the gradient and bulk Richardson numbers (R_i and R_B) for each level on Towers 2, 6, 110, and 313 collected in January, all years in the POR. Stull (1988) states that flow becomes turbulent when $R_i < 0.25$. Using this criterion, the results showed the tower layers were unstable over 90% of the time at Towers 2, 6 and 100, and 75% of the time at Tower 313. The high percentages of unstable cases did not appear representative of the climatological stability for January.

To examine these results further, Ms. Crawford determined the percentage of unstable values for each hour of the day at Towers 2 and 313, shown in Table 1. There was a clear diurnal signal in the values. In January, the sun rises locally at 0700-0715 EST and sets at 1745-1800 EST. In Table 1, the night hours between sunset and sunrise are in the left three columns, and the day hours between sunrise and sunset are in the right three columns. The overnight values remained steady with a slight increase in the midnight hours between 1100 and 0300 EST in both towers, and values were 10-15% lower at Tower 313. The percentages increase quickly after sunrise to 99-100% between 1000 and 1600 EST, and then dropped quickly to overnight values by sunset.

Table 1. Hourly frequencies in percent of $R_i < 0.25$ for Towers 2 and 313 in January 1995-2010.

Hour EST (UTC)	*2*	*313*	*Hour EST (UTC)*	*2*	*313*
19 (00)	71	57	**07 (12)**	73	54
20 (01)	70	57	**08 (13)**	82	63
21 (02)	71	59	**09 (14)**	97	90
22 (03)	71	61	**10 (15)**	100	99
23 (04)	73	63	**11 (16)**	100	100
00 (05)	76	62	**12 (17)**	100	100
01 (06)	78	64	**13 (18)**	100	100
02 (07)	76	62	**14 (19)**	99	100
03 (08)	77	62	**15 (20)**	99	100
04 (09)	74	58	**16 (21)**	99	100
05 (10)	74	57	**17 (22)**	94	96
06 (11)	74	58	**18 (23)**	78	64

The quick increase to 100% was likely due the surface-level instability created by solar heating of the ground . The cause of the slight increase in the steady values around midnight is unclear. Nonetheless, the percentages of unstable cases were still higher than expected for the overnight. Unstable R_i values occurred both day and night even when the region was under the influence of a strong, stable, high pressure center (Figure 1). Based on these results, Ms. Crawford concluded that the tower data could not be used to determine stability and, therefore, could not be used to stratify the data by stability.

It is possible that the CCAFS soundings can be used to determine boundary layer stability. Ms. Crawford sent the quality controlled (QC-d) soundings to Mr. Kienzle of ENSCO, Inc.'s GeoSystem Solutions Division to calculate the mixed layer (ML; Stull 1988) height using algorithms he developed for transport and diffusion models. The ML height will serve as the proxy for the height of the boundary layer.

On/Offshore Stratifications

Ms. Crawford determined the times of onshore and offshore flow using each tower wind sensor (Figure 2), and then calculated the hourly means of the winds, gust factors, and frequency for each flow pattern/month combination. Towers 2, 6, and 110 have two sensors at each height on opposing sides, NW and SE. The towers at pads 39A and B and Tower 41 have one sensor on each tower, but each pad has towers located on the NW and SE sides. This makes their configuration similar to Towers 2, 6, and 110. Ms. Crawford used the algorithms developed in Bauman (2010), which accounted for the sensor location relative to the tower and the wind directions:

Tower 2:

- Onshore if SE sensor direction is ≥ 46° and ≤ 225°; NW sensor direction used if SE sensor direction missing.

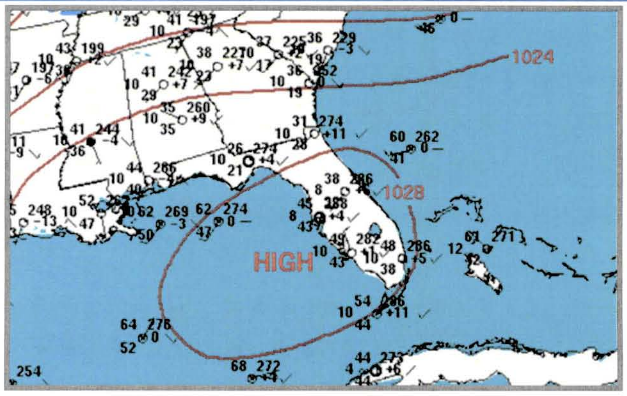


Figure 1. Surface weather map for 20 January 2003 at 0700 EST (1200 UTC) from http://www.hpc.ncep.noaa.gov/dailywxmap/.

- Offshore if NW sensor direction is ≥ 226° or ≤ 45°; SE sensor direction used if NW sensor direction missing.

Towers 6, 110, 41, and 39X:

- Onshore if NW sensor direction is ≥ 316° or ≤ 45°, or SE sensor direction is ≥ 46° and ≤ 135°.
- Offshore if NW sensor direction is ≥ 226° and ≤ 315°, or SE sensor direction is ≥ 136° and ≤ 225°.
- If direction from one side missing, direction from other side used.

Tower 108:

- Onshore if direction is ≥ 316° or ≤ 135°.
- Offshore if direction is ≥ 136° or ≤ 315°.

The onshore/offshore flow criteria for Tower 2 are different than for the other towers due to its location near the south end of CCAFS where the coastline is oriented NE-SW, approximately 45° to 225° (Figure 2). The coastline nearest Towers 6, 108, 110, 41, and 39A and B are oriented NW-SE, approximately 315° to 135°. To increase the sample size, Ms. Crawford added the condition to use the direction from the downwind sensor if the direction from the upwind sensor is missing. There were some conflicts for towers with two sides in which one sensor indicated one flow type and the other sensor showed the opposite. This usually occurred during transitions between onshore and offshore flow. In these cases, Ms. Crawford assigned the most recent unambiguous flow pattern.

Hourly Climatologies

Figure 3 shows the hourly climatologies of the 5-minute average and peak wind speeds (left) and the number of occurrences of each flow pattern for onshore and offshore flow at the 90-ft NW sensor on Tower 2 in January. The offshore average and peak wind speeds show the expected increase in values during the daytime hours (1200-2300 UTC), but the onshore values decreased by 1-3 kt from their nighttime values during the same time period. The main feature in number of occurrence curves is the marked increase in offshore flow events and decrease in onshore flow events beginning at midnight local time (0500 UTC) and peaking between 0400-0800 EST (0900-1300 UTC). This likely reflects the occurrence of the land breeze in the overnight hours known to occur over KSC/CCAFS.

The gust factor means and standard deviations shown in Figure 4 followed similar trends as the speed climatologies in Figure 3: relatively constant values during the night, increasing values with the sun-

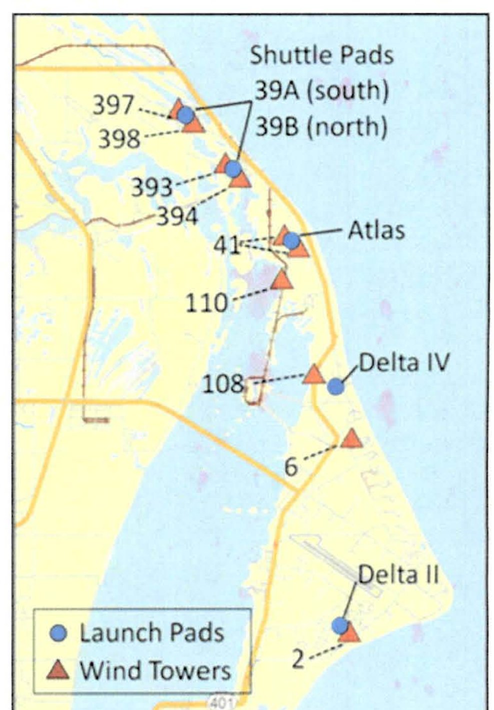


Figure 2. Map showing the locations of the launch pads and LCC wind towers.

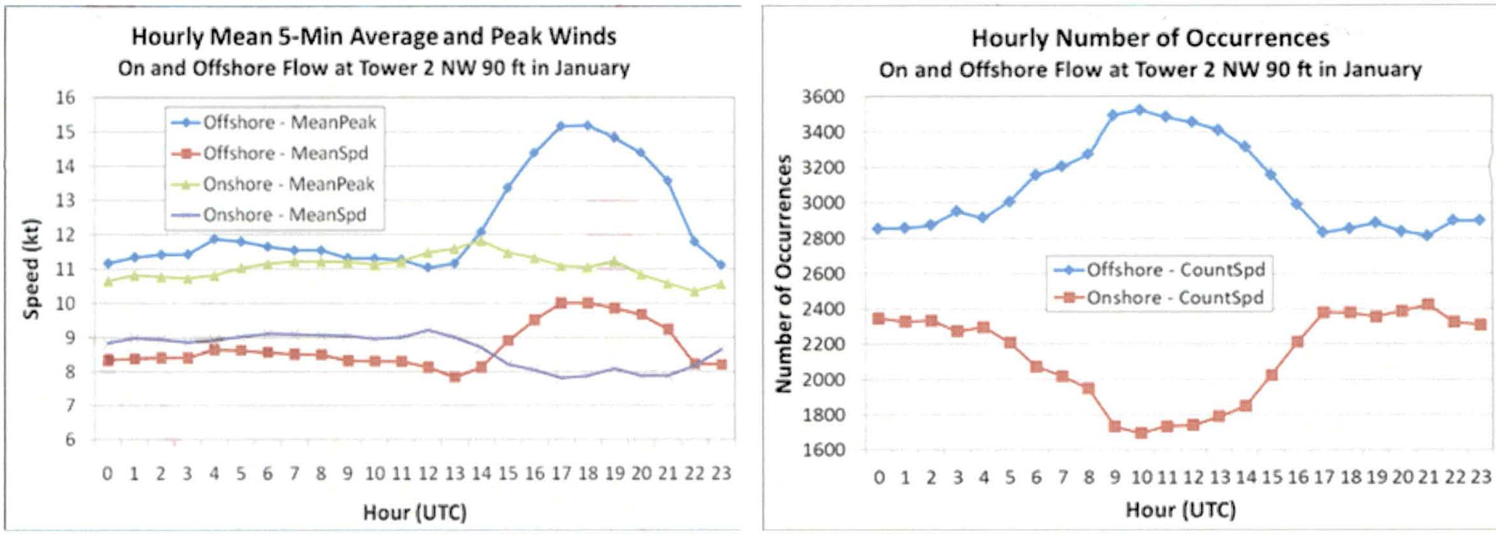


Figure 3. Hourly climatological values for the wind speeds at the 90-ft NW sensor on Tower 2 in January: (left) the hourly mean 5-minute average and peak winds and (right) the hourly number of occurrence of onshore and offshore flow. Offshore values are blue and red, and onshore values are green and purple in each chart.

rise to mid-day, and decreasing through sunset. The onshore mean values were consistently less than the offshore values, but the standard deviations were similar. Dr. Merceret compared the gust factor curves to a solar parameter for January. This solar parameter varies from 0 to 1 and depends on the sun angle for each hour and day of year (http://www.gcstudio.com/suncalc.html). Figure 4 also shows the solar parameter hourly curve calculated for 15 January (mid-month). There is a visual correlation between the GF and solar curves. Dr. Merceret will continue to explore the relationship between the solar parameter and the gust factor means and standard deviations.

Contact Ms. Crawford at 321-853-8130 or crawford.winnie@ensco.com for more information.

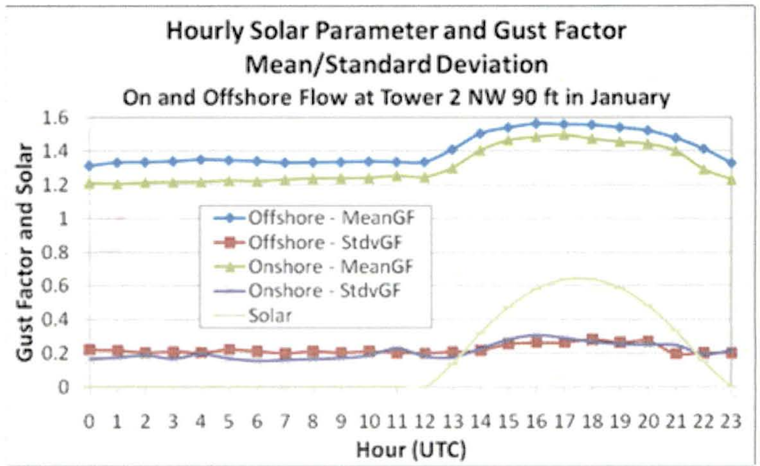


Figure 4. Hourly gust factor means and standard deviations at the 90-ft NW sensor on Tower 2 in January, and the solar parameter curve for January 15.

Situational Lightning Climatologies for Central Florida, Phase V (Dr. Bauman)

The threat of lightning is a daily concern during the warm season in Florida. Research has revealed distinct spatial and temporal distributions of lightning occurrence that are strongly influenced by large-scale atmospheric flow regimes. The 45 WS, SMG and National Weather Service in Melbourne, Fla. (NWS MLB) have the responsibility of issuing weather forecasts for airfields located in central Florida. SMG and 45 WS share forecasting responsibility for the SLF depending on the mission. The 45 WS has forecasting responsibility for the CCAFS Skid Strip and Patrick Air Force Base (PAFB) while the NWS MLB is responsible for issuing terminal aerodrome forecasts (TAF) for airports throughout central Florida. In the previous phase (Bauman 2009), Dr. Bauman calculated lightning climatologies for the SLF and eight other airfields in central Florida based on a 19-year record of cloud-to-ground (CG) lightning data from the National Lightning Detection Network (NLDN) for the warm season months of May through September (1989-2007). The climatologies included the probability of lightning at 5-, 10-, 20- and 30-NM distances from the center point of the runway at each site. The climatologies were stratified by flow regimes with probabilities depicted at 1-, 3-, and 6-hour intervals. This phase updates the previous work by adding 14 sites to the 9-site database including the CCAFS Skid Strip, PAFB and 12 commercial airports. It also adds three years of NLDN data resulting in a POR for the warm season months from 1989-2010. In addition to the flow regime stratification, moisture and stability stratifications will be added to separate more active from less active lighting days within the same flow regime.

New Sites

The NWS MLB requested an additional nine sites be added to the climatology to support adjacent NWS Weather Forecast Offices in Florida. Dr. Bauman agreed to add the sites if time permitted after he finished processing the first 23 sites. Dr. Bauman requested the NLDN data for May-September 1989-2010 from Mr.

Roeder of the 45 WS for the nine sites. The 14 WS prepared the NLDN data files and Dr. Bauman downloaded them from their servers.

PWAT Stratification

Dr. Bauman modified existing S-PLUS scripts to include the precipitable water (PWAT) stratification for each site using the PWAT thresholds from the closest sounding location: Jacksonville (JAX), Tampa (TBW), Miami (MFL) or CCAFS (AMU Quarterly Report Q1 FY11). The PWAT stratification threshold values varied by up to 13% among the four sounding locations in any given warm season month. He then generated new lightning climatologies for the 23 original sites using the PWAT stratifications.

Because the task was ahead of schedule, he processed the NLDN data for the additional nine sites requested by NWS MLB using existing S-PLUS scripts. He also completed the climatologies for 5 sites, resulting in completed climatologies for 28 of the 32 sites.

Upcoming Work

Dr. Bauman will finish the lightning climatologies for the remaining four sites and will update the graphical user interface (GUI) with the PWAT-stratified values and additional sites. He will deliver the updated GUI to the customers prior to the beginning of the 2011 warm season. He will then assess sounding stability stratifications that have a relatively high correlation to lightning occurrence as found in previous AMU work. This will only include stability parameters available to the forecasters in their weather analysis and display systems.

For more information contact Dr. Bauman at 321-853-8202 or bauman.bill@ensco.com.

Vandenberg Air Force Base North Base Wind Study (Mr. Wheeler)

The 30 WS states that terrain influences along the extreme northern fringes of Vandenberg Air Force Base (VAFB) make it difficult for forecasters to issue timely and accurate high wind warnings for that part of the base during northeasterly wind events. These events tend to occur during the winter or early spring when they are under the influence of the Great Basin high pressure weather regime. The LWOs have seen these rapid wind increases in Towers 60, 70 and 71 (Figure 3) along the northern edge of VAFB in excess of the 35 kt warning threshold. For this task, the 30 WS requested the AMU analyze data from days when these towers reported winds in excess of 35 kt and determine if there are any precursors in the observations that would allow the LWOs to better forecast and warn their operational customers of these wind events.

VAFB Wind Tower Database

Figure 5 is a Google Earth map showing the locations of all wind towers on VAFB. Towers 60, 70 and 71 along the northern part of VAFB are the primary wind towers Mr. Wheeler used for this study. The POR is January 2004 through March 2010. During this period the tower data came from two sensor types, each formatted differently. The data from January 2004 to October 2007 were from the mechanical (cup and vane) wind sensors and were archived every 5 minutes. The data from November 2007 through March 2010 were from the ultrasonic sensors and were archived every 1 minute.

Ms. Crawford extracted 5-minute peak wind speeds from the 1-minute ultrasonic data using S-PLUS. This process was needed so all the tower data would have the same 5-minute time resolution. Mr. Wheeler imported the new 5-minute data into the existing 2004-2007 Excel database so he could complete the analysis of each tower's peak wind direction and speed for each event. He created Excel charts that showed the wind direction and speed patterns to help him find precursors to high wind speed events. He also retrieved surface weather maps, 850 and 500 mb upper air maps, and VAFB sounding data for each of the event days from Plymouth State University (http://vortex.plymouth.edu/) and the National Centers for Environmental Prediction (NCEP) (http://www.hpc.ncep.noaa.gov/dailywxmap/) in order to categorize and detail the weather on each event day.

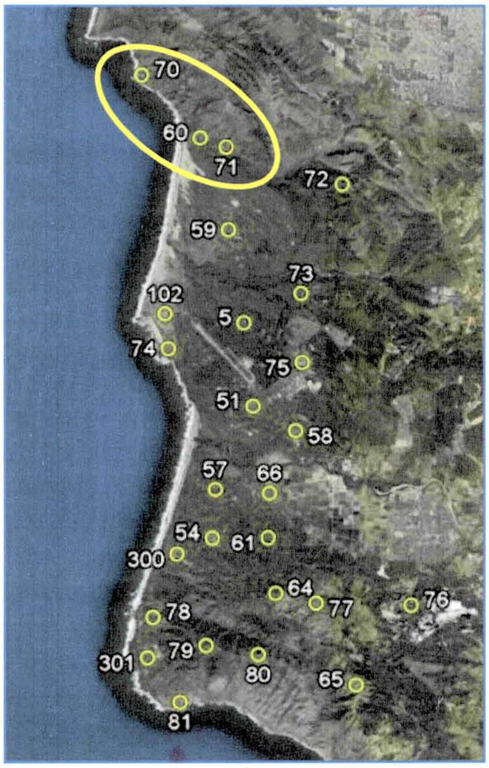


Figure 5. Google Earth map of the VAFB tower locations as yellow circles with white tower numbers. The towers for this task are surrounded by the yellow ellipse.

Wind Tower Events

The 30 WS identified 66 event days from their cool seasons (October-March) in the years 2004-2010. Of the 66 event days, several did not have any tower data and others did not have any observations that met the 35 kt criterion. There were only 30 event days in which the winds at the study towers met or exceeded 35 kt. Mr. Wheeler created Excel charts of wind direction and speed for each event day and wind roses for each event period. He analyzed the surface plots to determine the synoptic pattern and placement

of surface high pressure systems, and 850 and 500 mb charts to determine the strength of synoptic systems. He also created Google Earth maps to look for orographic changes that would cause a 35-kt-plus wind event at any of the three towers.

Data Analysis

Mr. Wheeler created Excel plots of wind direction and speed for each of the 30 event days. He noted a trend on most event days in which the prevailing winds at 54 ft would switch to the northeast prior to peak winds exceeding 35 kt. The timing between the switch and the 35-kt observations ranged from 10 minutes to 2 hours. The key similarity was that all wind gusts meeting or exceeding 35 kt were always from the northeast on each event day. Charts of peak wind direction and speed for each event day clearly show that the measured peak wind speeds were from a northeast trajectory.

Example Event Day

The 30 WS identified 28 November 2007 as one of their strong wind event days. Synoptic conditions on this day (Figure 6) showed high pressure dominating the Pacific Northwest with a ridge extending southeast into Nevada. With the ridge in this location, the surface winds should have been out of the east-southeast at VAFB.

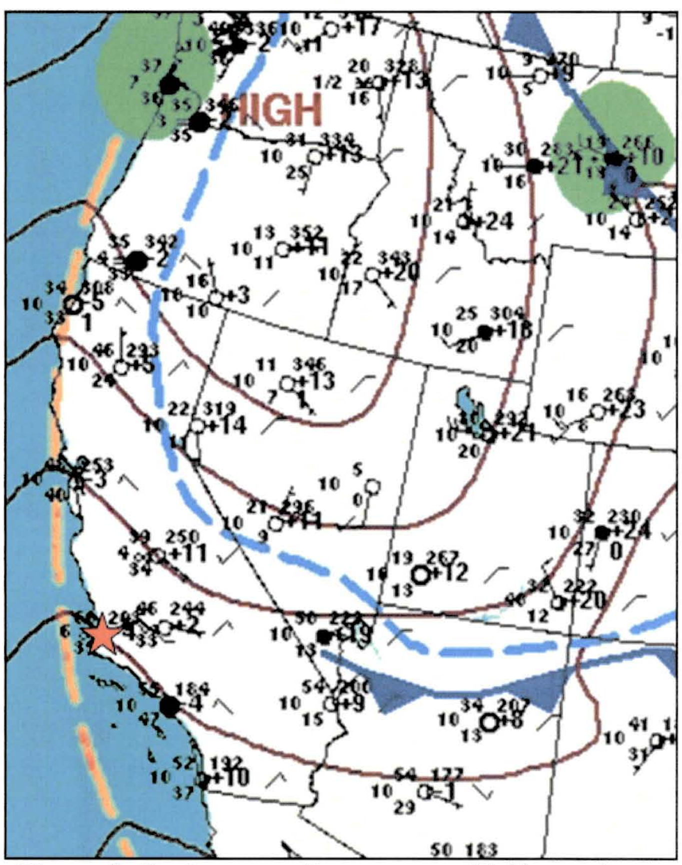
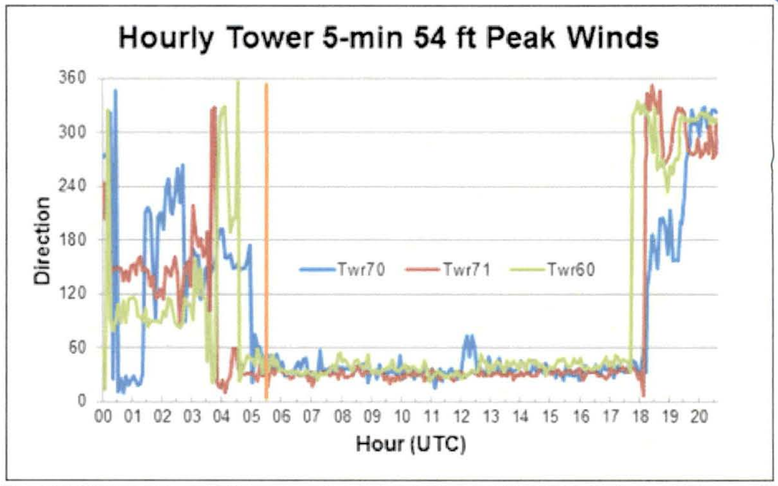


Figure 6. Surface weather map on 28 November 2007 at 1200 UTC High Pressure in the Pacific Northwest with a ridge toward Nevada. The red star in the lower-left marks VAFB. (http://www.hpc.ncep.noaa.gov/dailywxmap/).



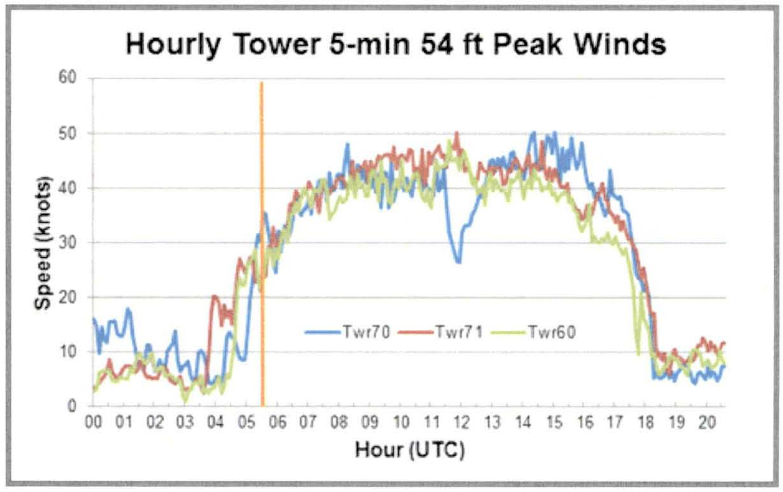


Figure 7. The peak wind direction (top) and speed (bottom) on 28 November 2007 0230-2000 UTC. The orange line marks the first 35 kt peak speed occurrence on Tower 70.

The wind direction and speeds for this event at Tower 70 are shown in Figure 7. This was the first northern tower to report the wind shift. The wind pattern at the three northern towers began with a southeast to south wind of around 10 kt. Around 0400 UTC; the 54-ft winds began backing to the northeast and increasing in speed. By 0430 UTC the winds at Tower 70 showed a distinct northeast shift with an increasing wind speed. At 0500 UTC, winds at Tower 70 become steady out of the northeast. By 0530 UTC, the peak wind speed at Tower 70 was 35 kt from the northeast. Over the next several hours the wind continued to gust above 40 kt. The wind shift at 0500 UTC occurred 30 minutes before the first recorded 35-kt peak wind. The winds weakened by 1800 UTC and shifted to the northwest.

Another way to show the wind flow and magnitude of peak wind speeds is to use wind rose charts. Figure 8 shows the wind rose for Tower 70 during the same time period as Figure 7. The red dots are wind speeds ≥35 kt at 54 ft. This chart clearly shows that all of the wind speeds ≥35 kt were from the northeast on this event day.

During the winter months when cold high pressure systems build in toward northern Nevada, as shown in Figure 6, surface winds at VAFB would generally be out of the northeast to east. A Google Earth terrain map of

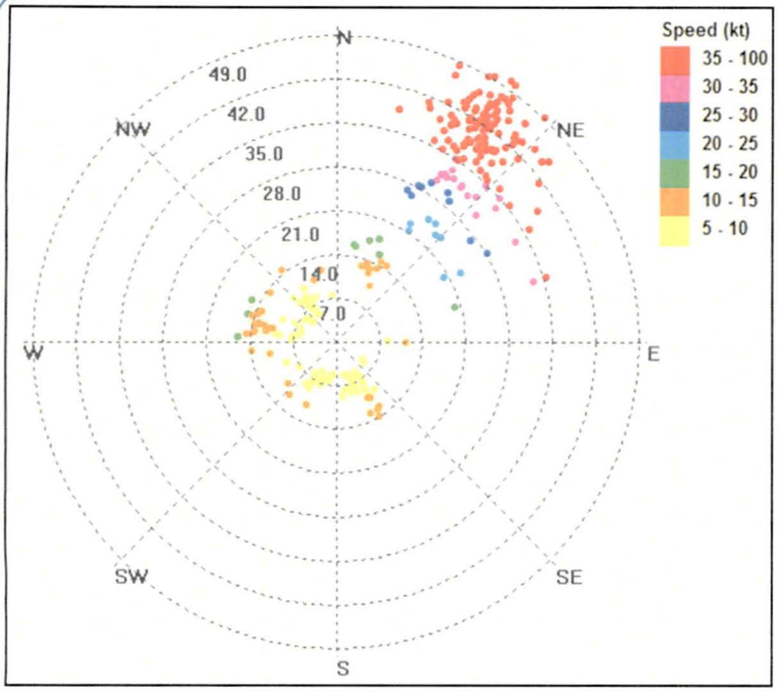


Figure 8. Wind rose charts for Tower 70, same time period as Figure 7. The red dots represent wind speeds ≥ 35 kt. Other wind speed ranges and associated colors are in the top right legend.

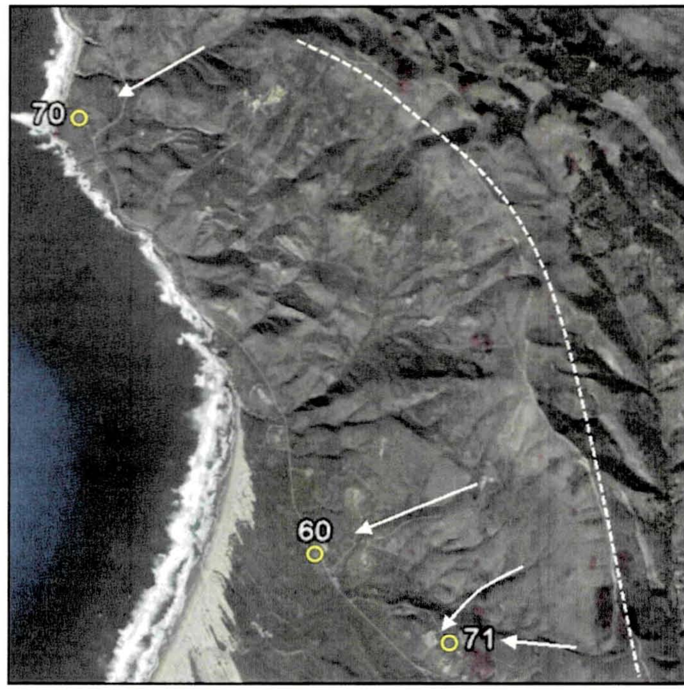


Figure 9. Google Earth terrain map showing the three northern VAFB tower locations as yellow circles with white tower numbers. The white dash line highlights top of range to the east and the white arrows highlight valleys that would enhance wind flow out of the northeast.

northern VAFB (Figure 9) highlights a north-south ridge to the east. The slope of the terrain shows valleys oriented southwest to northeast near each tower leading toward the top of the ridge. These valleys likely help focus and strengthen a northeast to east surface wind.

Recommendations

A northeast tower wind flow pattern was apparent on all of the 30 event days. Mr. Wheeler showed through his analysis that the cases in this task all showed an apparent shift of the surface winds to a northeast flow pattern 20 minutes to 2 hours before the winds reached 35 kt. The next step in developing a high-wind alert capability for VAFB would be the installation of a local mesoscale model that would incorporate all of the local data sets. The model should then be tested to see if it can forecast these types of events with a lead time of 2 to 24 hours. This would allow the meteorologist at VAFB to alert the operational customers in a timelier manner so protective action could be taken.

Status

Mr. Wheeler completed his review and analysis of the VAFB wind events and started writing the final report.

For more information contact Mr. Wheeler at 321-853-8205 or wheeler.mark@ensco.com

Upgrade Summer Severe Weather Tool Phase III (Dr. Watson)

The 45 WS Commander's morning weather briefing includes an assessment of the likelihood of local convective severe weather for the day. This forecast is provided in order to enhance protection of personnel and material assets of the 45th Space Wing, CCAFS, and KSC. The severe weather elements produced by thunderstorms include tornadoes, convective surface winds of 50 knots, and/or hail with a diameter of 0.75 inches. Forecasting the occurrence and timing of these phenomena during the warm season (May-September) is challenging for 45 WS operational personnel. In previous tasks, the AMU analyzed stability parameters and synoptic patterns from Central Florida severe weather days during 1989-2003 to determine which were important to severe weather development (Bauman et al. 2005). The AMU then created a hyper text markup language (HTML) tool using the important parameters and patterns to help determine the probability of issuing severe weather watches and warnings for the day. The HTML tool was replaced with a Meteorological Interactive Data Display System (MIDDS) GUI in a follow-on task (Wheeler 2009) that retrieved stability parameters and other information from MIDDS automatically, minimizing the forecaster's interaction with the tool. Later, the AMU updated the severe weather database with data from the years 2004-2009, re-analyzed the data to determine the important parameters, made appropriate adjustments to the index weights depending on the results of the analysis, and updated the MIDDS GUI (Wheeler 2010). For this task, the 45 WS requested the AMU upgrade the severe weather database by adding weather observations from 2010, update the verification data set with results from the summer of 2010, use statistical logistic regression analysis on the database and develop a new forecast tool if appropriate, and update the MIDDS GUI, if necessary.

Logistic Regression Analysis

Following Lambert and Wheeler (2005), Dr. Watson conducted predictor selection using S-PLUS, which has a built-in logistic regression function. She used a process called screening regression to determine which candidate predictors to include in the logistic regression equation. In this approach, predictors were added to the equation one at a time. At each step, the candidate predictor that created the biggest reduction in the residual deviance was chosen as the next predictor in the equation. Figure 10 shows the percent reduction in residual deviance from the NULL model as each predictor was added. The Total Totals (TT) reduced the residual deviance by the most (~8%) and was chosen as the first predictor in the equation. The second predictor was the flow regime, which brought the total reduction of residual deviance to ~13%. The Lifted Index (LI) and upper-level jet existence were the third and fourth predictors in the equation, respectively, producing the final reduction in residual deviance of 15%.

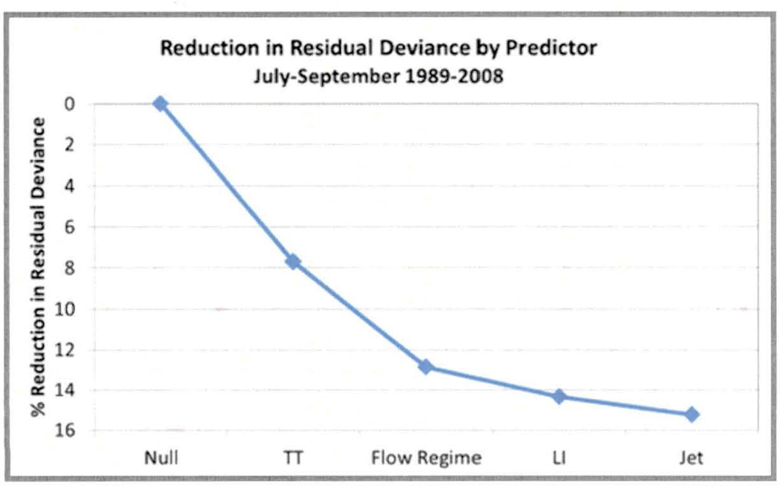


Figure 10. The total percent reduction in residual deviance from the NULL model as each predictor was added to the equation using the development dataset.

Logistic Regression Equation Performance

Dr. Watson compared the calculated forecast probabilities using the four predictors in Figure 10 and determined their performance using the binary severe weather observations and four tests that measure forecast performance. The tests included

- Mean Squared Error (MSE),
- Brier Skill Score (BSS),
- Distributions of the probability forecasts for days with and without severe weather, and
- Contingency table statistics.

The MSE is the mean of the squared differences between the forecast probabilities and the observations. The MSE for a perfect forecast is 0, with larger MSE indicating decreasing accuracy of the forecast. The MSE was computed for the logistic regression equation using the development and verification datasets. The MSE for the full development dataset was 0.10, which indicates skill in predicting severe weather. However, when the data were split into severe and non-severe events, the MSE was 0.61 and 0.03, respectively. Similarly, the MSE for the full verification dataset was 0.11, but 0.59 and 0.02 for severe and non-severe events, respectively. These results indicate that the equation was biased towards predicting non-events and failed to adequately predict severe weather events. The MSE was also computed for the Total Threat Score (TTS) using the verification dataset. The MSE for the full verification dataset was 0.07 and was 0.26 and 0.03 for severe and non-severe events, respectively. Based solely on MSE, the TTS was a better predictor of severe weather events than the logistic regression equation.

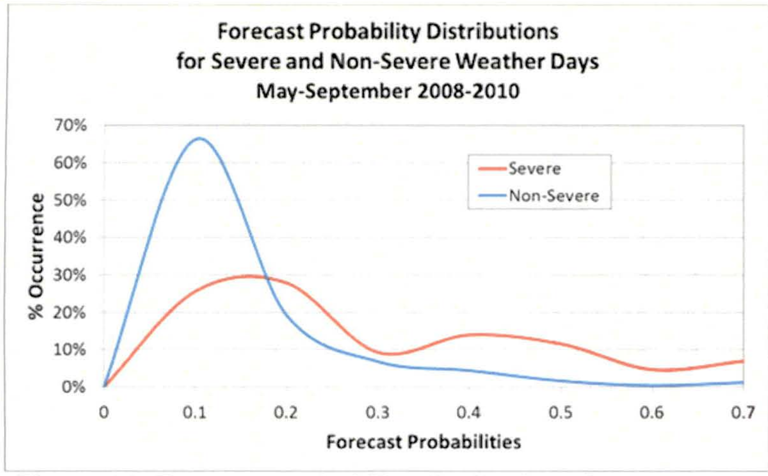


Figure 11. Forecast probability distributions for severe (red) and non-severe (blue) days in the verification data. The y-axis values are the frequency of occurrence of each probability value, and the x-axis values are the forecast probability values output by the equation.

The BSS measures the difference in skill of the logistic regression equation against a reference forecast. The BSS denotes a percent improvement (degradation) in skill of the equation over the reference forecast when it is positive (negative). The TTS for the verification dataset was used as the reference forecast. The BSS values for the verification dataset were -57% for the full dataset, -131% for the severe weather events, and 34% for non-severe weather. As with the MSE, these results indicate that the logistic regression equation is biased towards predicting non-events as the percent improvement for the non-severe weather is large. However, the percent degradation for predicting severe events is quite large, again indicating that TTS is a better tool for predicting severe weather.

The equation probability forecasts from the verification dataset were stratified by severe and non-severe weather days. The distribution of the probability values was calculated for each stratification. Figure 11 shows the probability distribution for severe days (red curve) and non-severe days (blue curve). If the equation performed well, the red (blue) curve would have a minimum (maximum) in the lower probability values that increase to a maximum (minimum) at the higher values. The non-severe weather days had a peak frequency near 65% at probability values of 0.1 and then decreased to near 0 at 0.6. It shows a high percentage of low probabilities for non-severe events and a low percentage of high probabilities as expected for good performance. The severe weather days had a small peak of 30% at probability values near 0.2 followed by a dip and then another small peak near 15% at probability values at 0.4. This indicates that the equation performed poorly for severe weather days. The maximum at 0.2 and minimum at 0.6 suggests the equation is under-forecasting severe weather events.

Table 2. Skill scores for the TTS and logistic regression forecasts.

Skill Score	***TTS***	***Logistic Regression***
POD	0.73	0.35
FAR	0.23	0.42
CSI	0.60	0.28
HSS	0.70	0.36
TSS	0.68	0.30

Table 2 shows the contingency table statistics for the TTS and logistic regression equation probabilities for the verification dataset. The Probability of Detection (POD) and Critical Success Index (CSI) are 1 for a perfect forecast and 0 for no skill, and vice versa for the False Alarm Rate (FAR). The Heidke Skill Score (HSS) and True Skill Statistic (TSS) are 1 for a perfect forecast, 0 for performance equal to a random forecast, and < 0 for performance worse than that of a random forecast. It is evident that the TTS outperforms the equation in every computed statistic.

Final Report

Dr. Watson completed the first draft of the final report. She then modified the report based on recommendations received from the internal AMU and external customer reviews. She submitted it for NASA approval and will have the report uploaded to the AMU website after that approval is received.

For more information contact Dr. Watson at 321-853-8264 or watson.leela@ensco.com

MESOSCALE MODELING

MesoNAM Verification Phase II (Dr. Watson)

The 45 WS LWOs use the 12-km resolution North American Mesoscale (NAM) model (MesoNAM) text and graphical product forecasts extensively to support launch weather operations. In Phase I of this task (Bauman 2010), the AMU measured the actual performance of the model objectively by conducting a detailed statistical analysis of model output compared to observed values. The model products included hourly forecasts from 0 to 84 hours based on model initialization times of 00, 06, 12 and 18 UTC. The objective analysis compared 3.5 years of MesoNAM forecast winds, temperature and dewpoint, as well as the changes in these parameters over time, to the observed values from the sensors in the KSC/CCAFS wind tower network. For this task, the 45 WS requested the AMU modify the current tool by adding an additional year of model output to the database and recalculating the verification statistics. The AMU will also update the current GUI with the new statistics. This tool helps the LWOs understand the model's performance when they use it to evaluate LCC during launch operations.

Wind Tower Data

Dr. Watson acquired the KSC/CCAFS wind tower data for the period February 2010 to February 2011 from the AMU archive, and used the AMU wind tower QC software to remove erroneous observations from the dataset. She used S-PLUS scripts written by Ms. Crawford to import and modify the QC'd wind tower observation files to remove unneeded time periods from the dataset for each tower and to fill in missing values with the appropriate designation. The locations of the towers used for the verification are shown on the map of KSC/CCAFS in Figure 12. Next, Dr. Watson modified a previously written S-PLUS script with the help of Ms. Crawford to compute the mean value for each observed parameter at the top of every hour using the observations from 30 minutes prior and 25 minutes after the hour.

MesoNAM Forecast Products

Dr. Watson requested and obtained the NCEP MesoNAM forecasts from Mr. Randy Nyman of ACTA, Inc. She imported the forecast files using S-PLUS scripts.

For more information contact Dr. Watson at 321-853-8264 or watson.leela@ensco.com

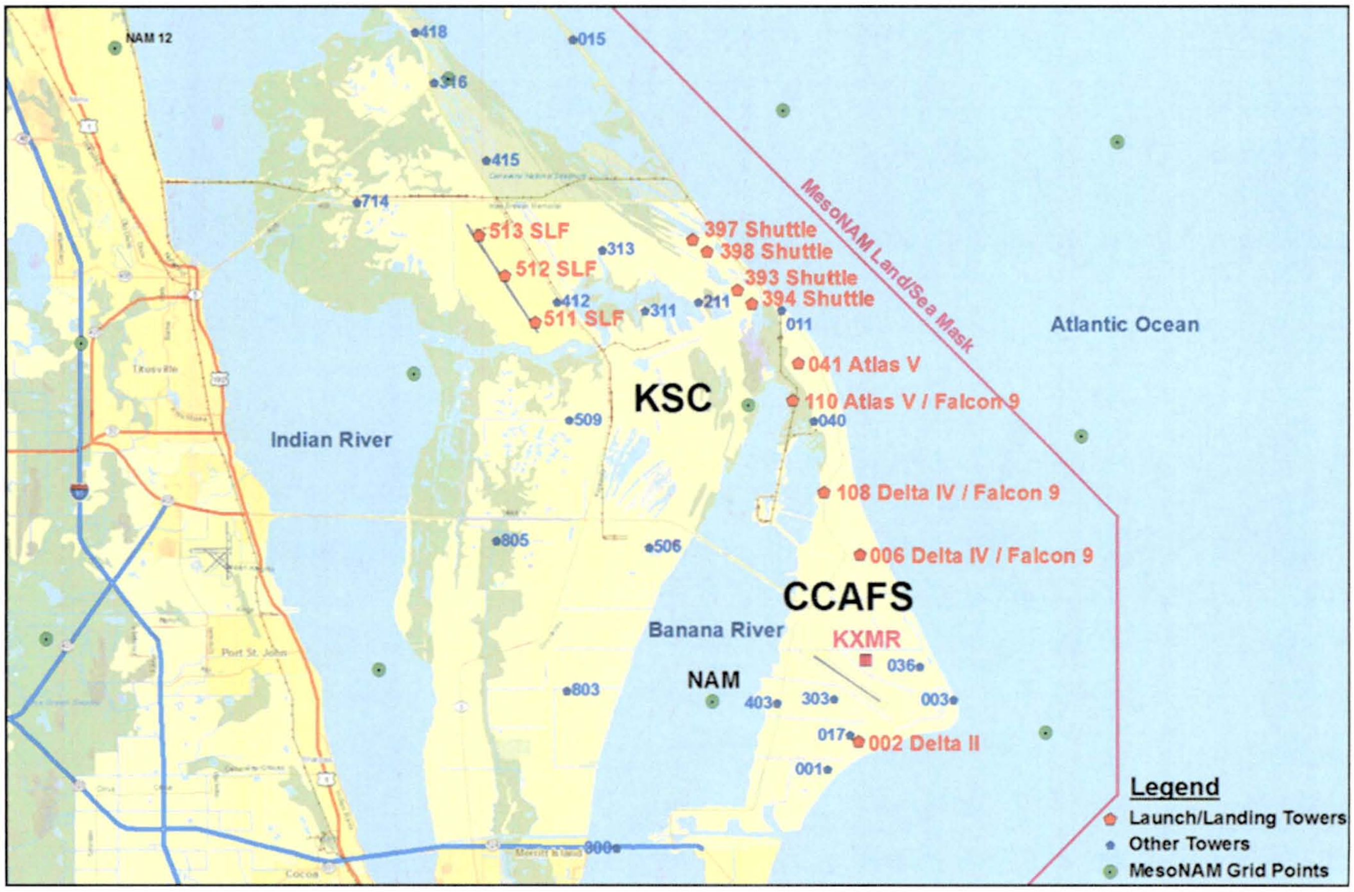


Figure 12. Map of KSC/CCAFS showing the wind tower locations as red pentagons labeled with tower number and the supported launch activity, MesoNAM model grid points as green circles, and the CCAFS weather station as a magenta square labeled KXMR (Bauman 2010, Figure 1).

REFERENCES

Bauman, W., M. Wheeler and D. Short, 2005: Severe Weather Forecast Decision Aid. NASA Contractor Report CR-2005-212563, Kennedy Space Center, FL, 50 pp. [Available from ENSCO, Inc., 1980 N. Atlantic Ave., Suite 830, Cocoa Beach, FL, 32931 and online at http://science.ksc.nasa.gov/amu/finalreports/severe-tool-final.pdf.]

Bauman, W. H. III, 2009: Situational Lightning Climatologies for Central Florida: Phase IV. NASA Contractor Report CR-2009-214763, Kennedy Space Center, FL, 39 pp. [Available from ENSCO, Inc., 1980 N. Atlantic Ave., Suite 830, Cocoa Beach, FL 32931 and http://science.ksc.nasa.gov/amu/final-reports/lightning-climo-phase4.pdf.]

Bauman, W., 2010: Verify MesoNAM Performance. NASA Contractor Report CR-2010-216287, Kennedy Space Center, FL, 31 pp. [Available from ENSCO, Inc., 1980 N. Atlantic Ave., Suite 830, Cocoa Beach, 32931, and at http://science.ksc.nasa.gov/amu/final.html.]

Crawford, W., 2010: Statistical Short-Range Guidance for Peak Wind Forecasts on Kennedy Space Center/Cape Canaveral Air Force Station, Phase III. NASA Contractor Report CR-2010-216281, Kennedy Space Center, FL, 33 pp. [Available from ENSCO, Inc., 1980 N. Atlantic Ave., Suite 830, Cocoa Beach, FL 32931 and http://science.ksc.nasa.gov/amu/final-reports/windstats-phase3.pdf.]

Insightful Corporation, 2007: *S-PLUS 8 for Windows User's Guide*, Insightful Corp., Seattle, WA, 584 pp.

Lambert, W., 2002: Statistical Short-Range Guidance for Peak Wind Speed Forecasts on Kennedy Space Center/ Cape Canaveral Air Force Station: Phase I Results. NASA Contractor Report CR-2002-211180, Kennedy Space Center, FL, 39 pp. [Available from ENSCO, Inc., 1980 N. Atlantic Ave., Suite 830, Cocoa Beach, FL 32931 and http://science.ksc.nasa.gov/amu/final-reports/windstats-phase1.pdf.]

Lambert, W., 2003: Extended Statistical Short-Range Guidance for Peak Wind Speed Analyses at the Shuttle Landing Facility: Phase II Results. NASA Contractor Report CR-2003-211188, Kennedy Space Center, FL, 27 pp. [Available from ENSCO, Inc., 1980 N. Atlantic Ave., Suite 830, Cocoa Beach, FL 32931 and http://science.ksc.nasa.gov/amu/final-reports/windstats-phase2.pdf.]

Lambert, W. and M. Wheeler, 2005: Objective lightning probability forecasting for Kennedy Space Center and Cape Canaveral Air Force Station. NASA Contractor Report CR-2005-212564, Kennedy Space Center, FL, 54 pp. [Available from ENSCO, Inc., 1980 N. Atlantic Ave., Suite 830, Cocoa Beach, FL, 32931, and online at http://science.ksc.nasa.gov/amu/final-reports/objective-ltg-fcst-phase1.pdf.]

Willett, J. C. and F. J. Merceret, E. P. Krider, J. E. Dye, T. P. O"Brien, W. D. Rust, R. L. Walterscheid, J. T. Madura, and H. J. Christian, 2010: *Rationales for the Lightning Flight Commit Criteria*, NASA/TP-2010-216291, 248 pp.

Stull, R. B, 1988: *An Introduction to Boundary Layer Meteorology.* Kluwer Academic Publishers, Dordrecht, The Netherlands, 670 pp.

Wheeler, M., 2009: Severe Weather and Weak Waterspout Checklist in MIDDS. NASA Contractor Report CR-2009 -214760, Kennedy Space Center, FL, 16 pp. [Available from ENSCO, Inc., 1980 N. Atlantic Ave., Suite 830, Cocoa Beach, FL, 32931 and online at http://science.ksc.nasa.gov/amu/final-reports/svr-wx-wkshtmidds.pdf.]

Wheeler, M., 2010: Upgrade Summer Severe Weather Tool in MIDDS. NASA Contractor Report CR-2010-216282, Kennedy Space Center, FL, 15 pp. [Available from ENSCO, Inc., 1980 N. Atlantic Ave., Suite 830, Cocoa Beach, FL, 32931 and online at http://science.ksc.nasa.gov/amu/final-reports/severe-tool-upgrade.pdf.]

AMU ACTIVITIES

AMU Chief's Technical Activities (Dr. Merceret, Dr. Huddleston)

Dr. Merceret began investigating errors in radar measurements of cloud location, height and thickness after concerns were raised by the Lightning Advisory Panel. He is examining error contributions from effects of propagation and beam geometry as well as the computational processes used by the radar product generation software. He requested climatological data on microwave index of refraction gradients near KSC/CCAFS and software to examine the propagation effects of those gradients. Dr. Merceret also began a literature search on the effects of beam geometry.

Dr. Merceret's work focused on effects of microwave propagation conditions on height measurements. This issue is also a concern for radiological contingency planning for the Mars Science Lander (MSL) scheduled for launch in November 2011. He generated a variety of soundings of the refractivity, N, based on climatological statistics of N at KSC/CCAFS provided by the Air Force. He analyzed these soundings using the ray tracing capability in a software package called Advanced Refractive Effects Prediction System (AREPS) obtained from the US Navy. Dr. Merceret's preliminary examination suggests that refractive height errors are unlikely to be of concern for evaluation of the lightning launch commit criteria, but probably will be of concern for MSL contingency operations.

In March, Dr. Huddleston took over the position of AMU chief from Dr. Merceret. Dr. Huddleston continued to familiarize herself with the needs of the 45 WS and the activities of the AMU. She corrected the 45 WS lightning strike location analysis software to account for an error that occurred if a lightning stroke occurred at precisely the same latitude and longitude as the center of the area of interest. Dr. Huddleston is working on a draft paper of the lightning probability algorithm for the Journal of Spacecraft and Rockets.

LIST OF ACRONYMS

14 WS	14th Weather Squadron
30 SW	30th Space Wing
30 WS	30th Weather Squadron
45 RMS	45th Range Management Squadron
45 OG	45th Operations Group
45 SW	45th Space Wing
45 SW/SE	45th Space Wing/Range Safety
45 WS	45th Weather Squadron
AFSPC	Air Force Space Command
AFWA	Air Force Weather Agency
AMU	Applied Meteorology Unit
BSS	Brier Skill Score
CCAFS	Cape Canaveral Air Force Station
CG	Cloud-to-Ground lightning
CSI	Critical Success Index
CSR	Computer Sciences Raytheon
FAR	False Alarm Rate
FSU	Florida State University
FY	Fiscal Year
GSD	Global Systems Division
GUI	Graphical User Interface
HSS	Heidke Skill Score
HTML	Hyper Text Markup Language
JAX	Jacksonville, Fla. 3-letter identifier
JSC	Johnson Space Center
KSC	Kennedy Space Center
LCC	Launch Commit Criteria
LI	Lifted Index
LWO	Launch Weather Officer
MesoNAM	12-km North American Mesoscale model
MFL	Miami, Fla. 3-letter identifier
MIDDS	Meteorological Interactive Data Display System
MSE	Mean Square Error
MSFC	Marshall Space Flight Center
NCEP	National Centers for Environmental Prediction
NLDN	National Lightning Detection Network
NOAA	National Oceanic and Atmospheric Administration
NWS MLB	National Weather Service in Melbourne, FL
PAFB	Patrick Air Force Base
POD	Probability of Detection
POR	Period of Record
PWAT	Precipitable Water
QC	Quality Control
SLF	Shuttle Landing Facility
SMC	Space and Missile Center
SMG	Spaceflight Meteorology Group
TAF	Terminal Aerodrome Forecast
TBW	Tampa, Fla. 3-letter identifier
TSS	True Skill Statistic
TT	Total Totals
TTS	Total Threat Score
USAF	United States Air Force
VAFB	Vandenberg Air Force Base

The AMU has been in operation since September 1991. Tasking is determined annually with reviews at least semi-annually.

AMU Quarterly Reports are available on the Internet at http://science.ksc.nasa.gov/amu/.

They are also available in electronic format via email. If you would like to be added to the email distribution list, please contact Ms. Winifred Crawford (321-853-8130, crawford.winnie@ensco.com).

If your mailing information changes or if you would like to be removed from the distribution list, please notify Ms. Crawford or Dr. Lisa Huddleston (321-861-4952, Lisa.L.Huddleston@nasa.gov).

Distribution

NASA HQ//AA/ W. Gerstenmaier
NASA KSC/AA/R. Cabana
NASA KSC/MK/L. Cain
NASA KSC/LX/P. Phillips
NASA KSC/PH/ R. Willcoxon
NASA KSC/PH-A2/D. Lyons
NASA KSC/PH/M. Leinbach
NASA KSC/PH/S. Minute
NASA KSC/VA/A. Mitskevich
NASA KSC/VA-2/C. Dovale
NASA KSC/KT-C/J. Perotti
NASA KSC/PH-3/J. Madura
NASA KSC/PH-3/F. Merceret
NASA KSC/PH-3/J. Wilson
NASA KSC/NEM50/ L. Huddleston
NASA JSC/WS8/F. Brody
NASA JSC/WS8/B. Hoeth
NASA JSC/WS8/ K. Van SpeyBroeck
NASA MSFC/EV44/D. Edwards
NASA MSFC/EV44/B. Roberts
NASA MSFC/EV44/R. Decker
NASA MSFC/EV44/H. Justh
NASA MSFC/MP71/G. Overbey
NASA MSFC/SPoRT/ G. Jedlovec
NASA DFRC/RA/E. Teets
NASA LaRC/M. Kavaya
45 WS/CC/E. Borelli
45 WS/DO/L. Shoemaker
45 WS ADO/W. Whisel
45 WS/DOR/M. McAleenan
45 WS/DOR/M. Buchanan
45 WS/DOR/K. Josephson
45 WS/DOR/R. Parker
45 WS/DOR/F. Flinn
45 WS/DOR/ T. McNamara
45 WS/DOR/J. Tumbiolo
45 WS/DOR/K. Winters
45 WS/DOR/D. Craft
45 WS/SYA/J. Saul
45 WS/SYR/W. Roeder
45 RMS/CC/T. Rock
45 SW/CD/G. Kraver
45 SW/SELR/K. Womble
45 SW/XPR/R. Hillyer
45 OG/CC/D. Sleeth
45 OG/TD/C. Terry
CSR 4500/J. Osier
CSR 4500/T. Long
CSR 7000/M. Maier
SLRSC/ITT/L. Grier
SMC/RNP/M. Erdmann
SMC/RNP/T. Nguyen
SMC/RNP/R. Bailey
SMC/RNP(PRC)/K. Spencer
HQ AFSPC/A3FW/J. Carson
HQ AFWA/A3/M. Surmeier
HQ AFWA/A3T/S. Augustyn
HQ AFWA/A3T/D. Harper
HQ AFWA/16 WS/WXE/ J. Cetola
HQ AFWA/16 WS/WXE/ G. Brooks
HQ AFWA/16 WS/WXP/ D. Keller
HQ USAF/A30-W/R. Stoffler
HQ USAF/A30-WX/ C. Cantrell
HQ USAF/Integration, Plans, and Requirements Div/ Directorate of Weather/ A30-WX
NOAA "W/NP"/L. Uccellini
NOAA/OAR/SSMC-I/J. Golden
NOAA/NWS/OST12/SSMC2/ J. McQueen
NOAA Office of Military Affairs/ M. Babcock
NWS Melbourne/B. Hagemeyer
NWS Melbourne/D. Sharp
NWS Melbourne/S. Spratt
NWS Melbourne/P. Blottman
NWS Melbourne/M. Volkmer
NWS Southern Region HQ/"W/ SR"/S. Cooper
NWS Southern Region HQ/"W/ SR3"/D. Billingsley
NWS/"W/OST1"/B. Saffle
NWS/"W/OST12"/D. Melendez
NWS/OST/PPD/SPB/P. Roohr
NSSL/D. Forsyth
30 WS/DO/J. Roberts
30 WS/DOR/D. Vorhees
30 WS/SY/M. Schmeiser
30 WS/SYR/G. Davis
30 SW/XPE/R. Ruecker
Det 3 AFWA/WXL/K. Lehneis
NASIC/FCTT/G. Marx
46 WS//DO/J. Mackey
46 WS/WST/E. Harris
412 OSS/OSW/P. Harvey
412 OSS/OSWM/C. Donohue
UAH/NSSTC/W. Vaughan
FAA/K. Shelton-Mur
FSU Department of Meteorology/H. Fuelberg
ERAU/Applied Aviation Sciences/C. Herbster
ERAU/J. Lanicci
NCAR/J. Wilson
NCAR/Y. H. Kuo
NOAA/FRB/GSD/J. McGinley
Office of the Federal Coordinator for Meteorological Services and Supporting Research/ R. Dumont
Boeing Houston/S. Gonzalez
Aerospace Corp/T. Adang
ITT/G. Kennedy
Timothy Wilfong & Associates/ T. Wilfong
ENSCO, Inc/J. Clift
ENSCO, Inc./E. Lambert
ENSCO, Inc./A. Yersavich
ENSCO, Inc./S. Masters